Calculating the Efficiency of Solar Cells

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Calculating the Efficiency of Silicon Solar Cell

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Abstract

The aim of this paper is to understand how the solar cell works and how the performance of the cell can be analyzed in terms of basic parameters. The single junction crystalline silicon solar cell with (np) type has been studied with analytical method, for three regions of solar cell, which are emitter, base and space charge region (SCR) region. By solving solar cell's equations: Poisson's equation, current density equations, and continuity equations for both types of charge carriers, the results were obtained for each of the current contribution for parts of the cell, internal quantum efficiency, internal spectral response, and the characteristic I-V curve of cell. While I-V curve shows the electrical characteristics of a solar cell, by determining the solar cell's output performance and solar efficiency, the spectral response and quantum efficiency curves show how the cell react with the light spectrum. From I-V curve the efficiency of the cell is proportional to the value of the three main photovoltaic parameters: short circuit current I_{sc}, open circuit voltage V_{oc}, fill factor FF and efficiency η have been determined. The result shows that the base component has the main contributing to the total current in almost all wavelengths except in the shorter wavelengths, where the emitter layer contribution dominates. The efficiency of the cell obtained to be 13%.

Keywords: solar cell, silicon, I-V curve, quantum efficiency
Discipline: Physics

INTRODUCTION

With the increasing consumption of non-renewable energy sources and their adverse effect to the environment, the search for renewable energy sources must be carried out to meet the increased demand for energy.

Sun is one of the most important sources, where its illuminates our planet by energy which is 8000 times more than the current rate of global consumption of energy [1]. One of the solar energy conversion technologies is 'Photovoltaic Technique'. This technique directly converts the sunlight into electricity using a unique device known as solar cell.

The mono-junction silicon solar cell is formed by a very thin layer n-type region is called the emitter as a front surface, and a thick layer and less doped p-type region is called the base as a back surface (see Figure 1). When n-type and p-type put together, the depletion region formed, which is empty form free carriers [2].

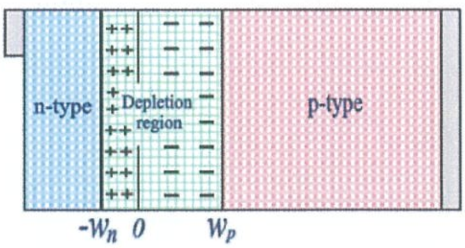

Figure 1. Simple structure of solar cell

When sunlight illuminates solar cells, the electron-hole pairs generates inside the cell. Electric field at the pn junction works to separate the electrons to n-type and the holes to the p-type. Then the front grid contacts work to pull electrons to external circuit to dissipated their energy, then come back to the base region to recombine again with holes, waiting for another photon from the sun to generate new pairs.

THEORY

As solar cell is semiconductor device, so it is underlying to semiconductor equations. There are five non-linear differential equations [2]. These equations has been solved analytically by using suitable boundary condition [3]. The calculations involved the light generated current for three parts of cell, dark current, internal quantum efficiency, internal spectral response, and I-V curve respectively as following:

1) Light generated current density in emitter, base and depletion region

$$J_E(\lambda)=\frac{q\alpha\phi_o(1-R)L_p}{(\alpha L_p)^2-1}\times\left[-\alpha L_p e^{-\alpha w_e}+\frac{S_e\frac{L_p}{D_p}+\beta L_p-e^{-\alpha w_e}\left(S_e\frac{L_p}{D_p}\cosh\frac{w_e}{L_p}+\sinh\frac{w_e}{L_p}\right)}{\cosh\frac{w_e}{L_p}+S_e\frac{L_p}{D_p}\sinh\frac{w_e}{L_p}}\right] \quad (1)$$

$$J_B(\lambda)=\frac{q\alpha\phi_o'(1-r)L_n}{(\alpha L_n)^2-1}\times\left[-\alpha L_n-\frac{S_b\frac{L_n}{D_n}+\left(\cosh\frac{w_b}{L_n}-e^{-\alpha w_b}\right)+\sinh\frac{w_b}{L_n}+\alpha L_n e^{-\alpha w_b}}{\cosh\frac{w_b}{L_n}+S_b\frac{L_n}{D_n}\sinh\frac{w_b}{L_n}}\right] \quad (2)$$

$$I_{SCR}(\lambda)=qF(1-R)\exp(-\alpha xj)(1-\exp(-\alpha w_D)) \quad (3)$$

2) Dark current density in emitter and base

$$J_{darkE}=q\frac{n_i^2 D_p}{N_D L_p}\left[\frac{S_e\frac{L_p}{D_p}\cosh\frac{w_e}{L_p}+\sinh\frac{w_e}{L_p}}{S_e\frac{L_p}{D_p}\sinh\frac{w_e}{L_p}+\cosh\frac{w_e}{L_p}}\right]\left[e^{\frac{V}{V_T}}-1\right] \quad (4)$$

$$J_{darkB}=q\frac{n_i^2 D_n}{N_A L_n}\left[\frac{S_b\frac{L_n}{D_n}\cosh\frac{w_b}{L_n}+\sinh\frac{w_b}{L_n}}{S_b\frac{L_n}{D_n}\sinh\frac{w_b}{L_n}+\cosh\frac{w_b}{L_n}}\right]\left[e^{\frac{V}{V_T}}-1\right] \quad (5)$$

3) Total current density

$$J=J_L-J_{dark} \quad (6)$$

4) Internal Quantum Efficiency (IQE)

$$IQE=\frac{J_L}{q\varphi_o(1-R)} \quad (7)$$

5) Internal Spectral Response (ISR)

$$ISR=\frac{J_L}{F(1-R)} \quad (8)$$

The cell parameters chosen for the simulation for the present model are summarized in Table 1.

Table 1. Parameters used in the simulation

Parameter	Value	Unit
n_i Intrinsic carrier concentration	1.45×10^{10}	cm^{-3}
N_D Donor carrier concentration	1×10^{16}	cm^{-3}
N_A Acceptor carrier concentration	1×10^{16}	cm^{-3}
L_n Diffusion length in base	162×10^{-4}	Cm
L_p Diffusion length in emitter	0.43×10^{-4}	cm
D_n Diffusion coefficient in base	36.33	cm^2/s
D_p Diffusion coefficient in emitter	3.4	cm^2/s
S_e Surface recombination velocity in emitter	2×10^5	cm/s
S_b Surface recombination velocity in base	1×10^3	cm/s
w_e Emitter thickness	0.3×10^{-4}	cm
w_b Base thickness	300×10^{-4}	cm
α Absorption coefficient	From database of Silicon [4,5]	cm^{-1}
φ_0 Spectral photon flux in emitter		$\#/cm^2\mu ms$
φ'_0 Spectral photon flux in base		$\#/cm^2\mu ms$
R Reflectivity of Silicon		___

RESULTS

Cell that has been studied in this research, was np-type mono-crystalline single junction solar cell, with equal doping concentration, where the donor concentration is equal to the acceptor concentration $N_D = N_A = 10^{16}\ cm^{-3}$.

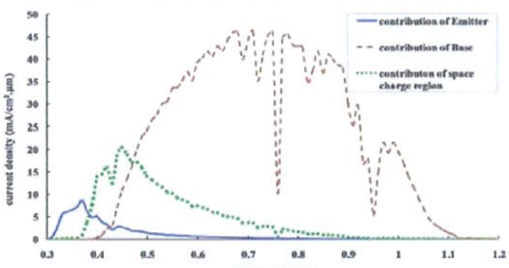

Figure 2. Contribution parts of cell in light generated current.

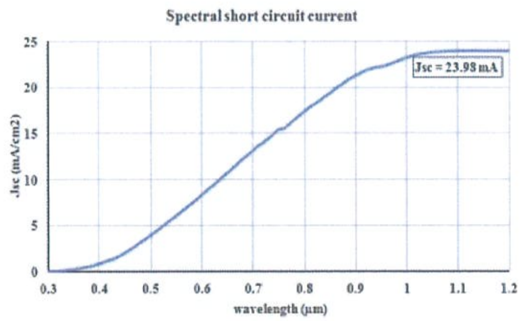

Figure 3. Spectral short circuit current density.

Figure 2 shows the contribution of emitter, base and space charge regions in generated current density. The base component is the main component contributing to the total current in almost all wavelengths except in the shorter wavelengths, where the emitter layer contribution dominates. The contribution of space charge density is medium between emitter and base regions.

Figure 3 shows the spectral current density for generated light and dark current where the current maximum value reached to 24 mA.

Figure 4 shows the Internal Quantum Efficiency (IQE) curve. The internal quantum efficiency has a maximum of around 98% at 0.7μm of wavelength and fades away from the maximum value at the two ends of the cell; this reduction is because of the surface recombination velocity at front and back surface of cell, and due to reach to the band-gap wavelength of silicon.

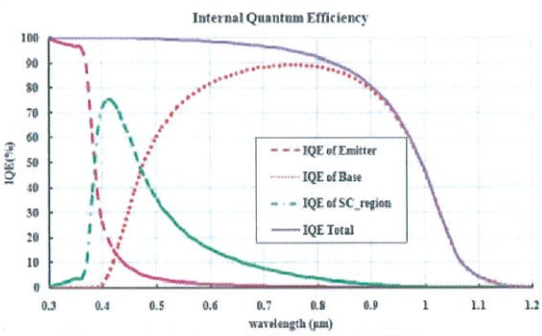

Figure 4. Internal Quantum Efficiency

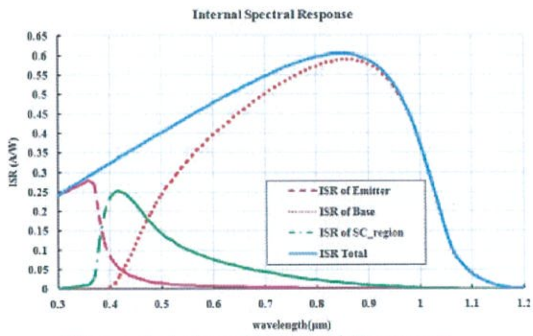

Figure 5. Internal Spectral Response

Figure 5 shows the internal spectral response, has a maximum of around 0.62A/W at 0.8μm where at short wavelengths are absorbed at the beginning of the spectrum thus, the response spectrum is reduced. At medium wavelengths, the cell is act as the ideal cell and at long wavelengths, the spectral response tends to zero.

Figure 6 shows the I-V characteristic curve of solar cell where the basic parameters of solar cell are illustrated in Table 2.

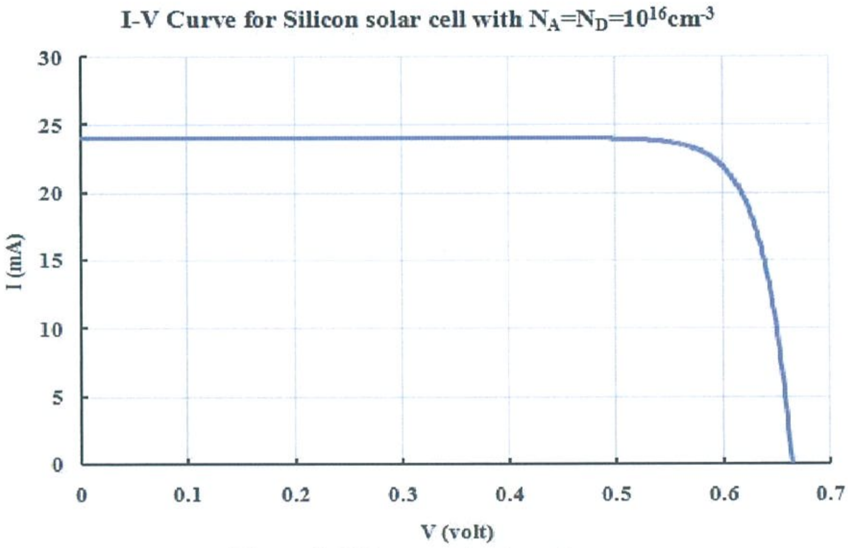

Figure 6. I-V curve of solar cell

Table 2. Basic parameters of cell

Area of cell = $1cm^2$	
Power point at 0.58 volt	
V_{mp} (volt)	0.58
I_{mp} (mA)	23.10
V_{oc} (volt)	0.66
I_{sc} (mA)	24.00
$FF = (V_{mp}*I_{mp})/(V_{oc}*I_{sc})$	84.5
$P_{out} = V_{mp}*I_{mp}$	0.13
P_{in} for $1cm^2$	0.01
$\eta = (P_{out}/P_{in})*100$ %	13.5 %

CONCLUSION

In this paper, we analyzed the contribution of each part of cell in electrical power cell. This would contribute to improve the design and performance of the solar cell. The depending of solar cell current on doping concentration depends on other variables, which are a thickness of active region, positions of carriers, diffusion coefficients and carrier lifetime of solar cell. With a deeper study of what is happening inside the cell and how to get the largest possible number of charge carriers would raise the efficiency of solar cell.

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